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RESEARCH SENSORS

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ABSTRACT

The work described here is part of a program (Englund and Seasholtz, 1988) to develop sensors and sensing techniques for research applications on aircraft turbine engines. In general, the sensors are used to measure the environment at a given location within a turbine engine or to measure the response of an engine component to the imposed environment. Locations of concern are generally in the gas path and, for the most part, are within the hot section. Specific parameters of concern are dynamic gas temperature, heat flux, airfoil surface temperature, and strain on airfoils and combustor liners. To minimize the intrusiveness of surface-mounted sensors, a considerable effort has been expended to develop thin-film sensors for surface temperature, strain, and heat flux measurements. In addition, an optical system for viewing the interior of an operating combustor has been developed. Most of the work described is sufficiently advanced that sensors have been used and useful data have been obtained. The notable exception is the work to develop a high-temperature static strain measuring capability; this work is still in progress. The work described here has been done at NASA Lewis Research Center and at other institutions, under various contracts and grants.

HIGH-TEMPERATURE INSTRUMENTATION FOR HOT SECTION APPLICATIONS

The work described here is part of a program to develop instrumentation for research applications on aircraft turbine engines. In general, the instrumentation is used to either measure the environment at a given location within a turbine engine or to measure the response of an engine component to the imposed environment. Locations of concern are generally within the gas path and, for the most part, are within the hot section of the engine. Since this instrumentation is used for research testing as opposed to operational use, a sensor lifetime of the order of 50 hr is considered sufficient. The work described here was done at NASA Research Center and at various other institutions, under various contracts and grants.

INSTRUMENTATION FOR RESEARCH MEASUREMENTS ON AEROPROPULSION SYSTEMS:

- **DYNAMIC GAS TEMPERATURE MEASURING SYSTEMS**
- **COMBUSTOR VIEWING SYSTEM**
- **HEAT FLUX SENSORS**
- **THIN-FILM SENSORS**
- **HIGH-TEMPERATURE STRAIN MEASURING SYSTEMS**

DYNAMIC GAS TEMPERATURE MEASURING SYSTEM

One of the most important environmental parameters in a turbine engine hot section is gas temperature. Normally only time-average temperature is measured. Fluctuations in gas temperature are, however, of great concern for hot section durability and combustor modeling activities. In this measuring system (Elmore et al., 1983, 1984, 1986a, and 1986b; and Stocks and Elmore, 1986), a probe with two wire thermocouples of different diameters provides dynamic signals with limited frequency response. Comparing these signals over a range of frequencies makes it possible to generate a compensation spectrum sufficient to provide compensated temperature data at frequencies up to 1000 Hz.

- **MEASURES GAS TEMPERATURE FLUCTUATIONS AT THE EXIT OF A TURBINE ENGINE COMBUSTOR**
- **A TWO-ELEMENT PROBE PROVIDES DATA TO PERMIT ACCURATE FREQUENCY COMPENSATION**

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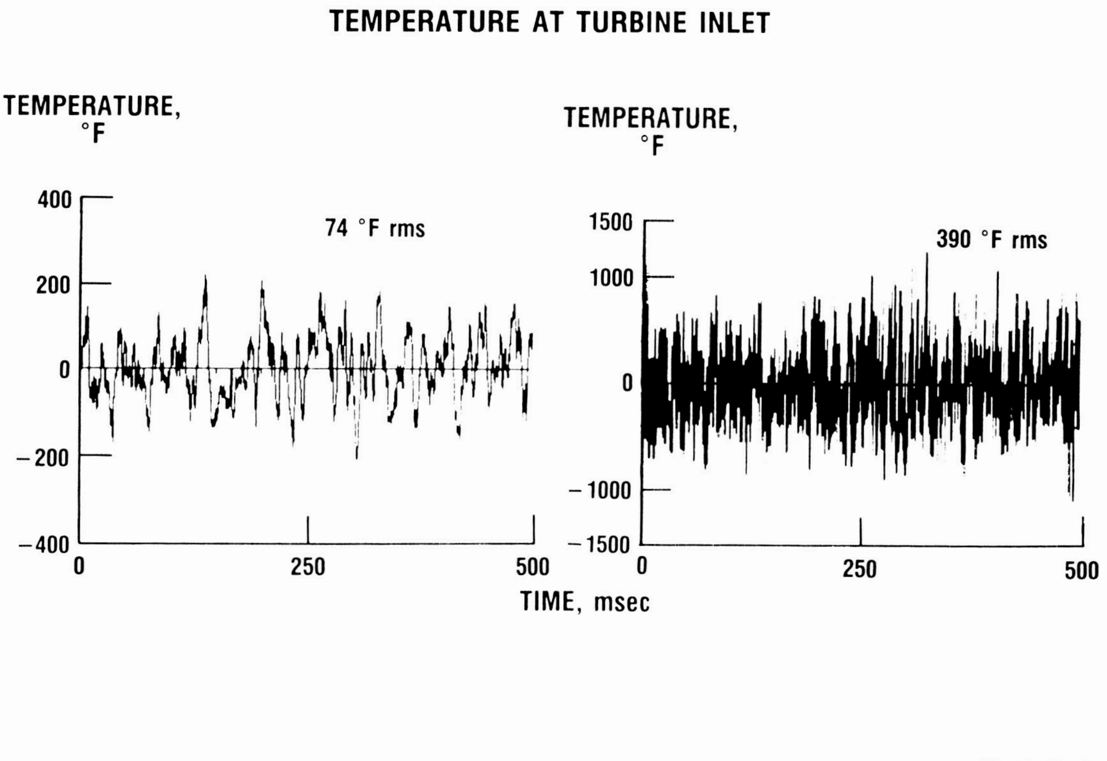
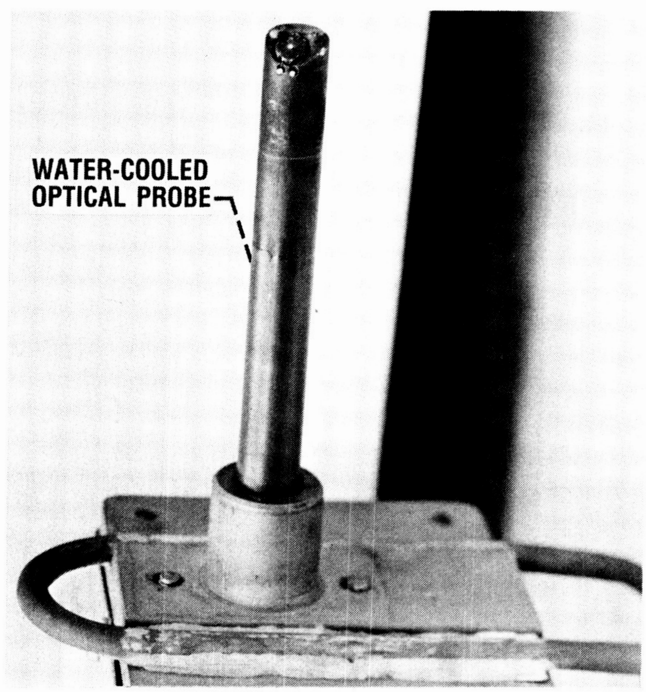
DYNAMIC GAS TEMPERATURE MEASUREMENT

This figure shows dynamic gas temperature data obtained from a probe at the turbine inlet of a PWA F-100 engine operating at an intermediate power setting with an average turbine inlet gas temperature of 1700 °F. The plot on the left is the dynamic signal from a 0.003-in.-diameter wire thermocouple with no frequency compensation. The rms value of the temperature fluctuation is 74 °F. The plot on the right is the compensated signal from the same thermocouple. The rms value of the temperature fluctuation is 390 °F and the peak-to-peak fluctuation is ±900 °F. Such a large temperature fluctuation implies that there are filaments of primary combustion gas and dilution gas within the combustor exhaust stream.



COMBUSTOR VIEWING SYSTEM

The Combustor Viewing System (Morey, 1984 and 1985) was designed to provide recorded images of the interior of a combustor during operation; the objective was to produce a visual record of some of the causes of premature hot section failure. The system consists of a water-cooled optical probe (shown below), a probe actuator, an optical interface unit that couples the probe to cameras and to an illumination source, and system controls. The probe is 0.5 in. in diameter, small enough to fit into an igniter port. The actuator provides ±180° of rotation and radial insertion of up to 3 in. Both wide and narrow fields of view and different viewing axes are provided from two different probes. The probes are water cooled and gas purged and can operate within the primary combustion zone of a combustor.



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HEAT FLUX SENSORS

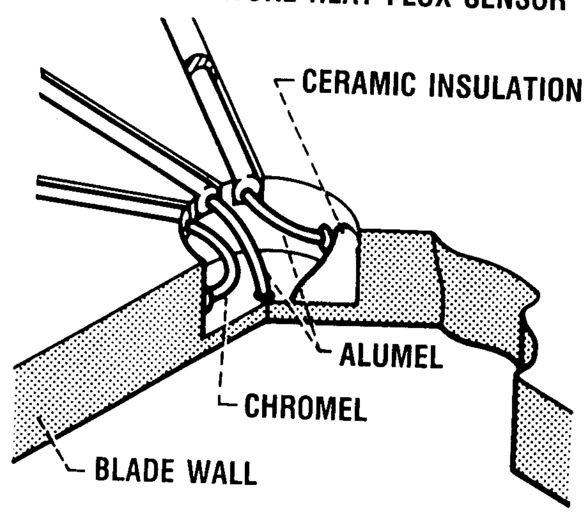
An environmental parameter of interest for hot section durability is heat flux. We have developed miniature heat flux sensors which can be welded into combustor liners (Atkinson and Strange, 1982; and Atkinson et al., 1983) and built into cooled turbine airfoils (Atkinson et al., 1984). This figure shows one sensor configuration based on the Gardon gage design. An innovation in these sensors is the use of the burner liner or airfoil material as part of a differential thermocouple circuit. Calibration tests (Atkinson and Strange, 1982; and Holanda, 1984) on these materials showed that this technique could provide acceptable signals. The differential thermocouple simplifies construction and permits a direct measurement of the differential temperature proportional to heat flux. These miniature heat flux sensors must be calibrated over the temperature range in which they will be used.

- **MEASURE HEAT FLUX ON BURNER LINERS AND TURBINE AIRFOILS**
- **MINIATURE WIRE THERMOCOUPLE SENSOR:**

  WELD INTO BURNER LINERS
  BUILD INTO AIRFOILS

- **SENSOR BODY PART OF THERMOCOUPLE CIRCUIT**
- **CALIBRATION SYSTEM REQUIRED**

HIGH-TEMPERATURE HEAT FLUX SENSOR



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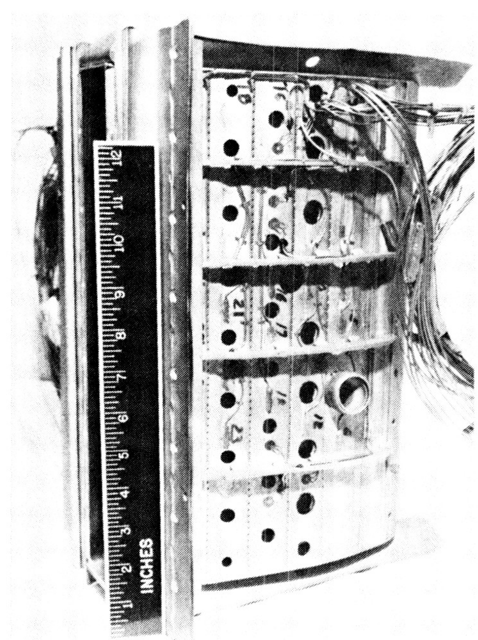
COMBUSTOR SEGMENT INSTRUMENTED WITH HEAT FLUX SENSORS

This photograph shows a segment of a combustor liner which has been instrumented with six heat flux sensors. The sensors are 0.3-in.-diameter disks with thermocouple leads radiating from the edge of the disk. The actual sensor part of the unit is at the center of the disk and is only 0.06 in. in diameter. The sensors are individually calibrated and then welded into holes cut in the liner. Tests on combustors such as this one have produced useful heat flux data over a range of combustor operating conditions (Atkinson et al., 1985a). Similar sensors built into turbine airfoils have been less successful because of the sensitivity of these sensors to temperature or heat flux gradients, which are more prevalent in turbine airfoils (Atkinson et al., 1985b). Sensor designs that are less sensitive to gradients have been examined but have not yet been put into use.



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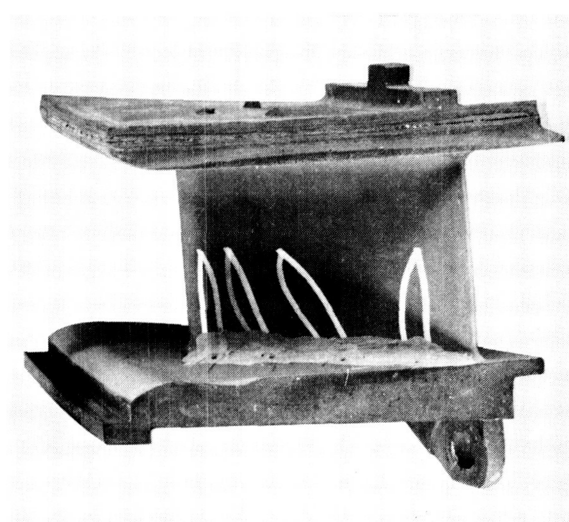
THIN-FILM THERMOCOUPLES

Lewis has been the major advocate and sponsor for development of thin-film sensors for turbine engine applications. Sensors applicable to turbine engines include temperature sensors, strain gages, and heat flux sensors. Thin-film thermocouples for measuring the surface temperature of a cooled turbine airfoil are shown here. The surface of the vane is covered with Al_2O_3 thermally grown from an anticorrosion coating and augmented with sputtered Al_2O_3. Platinum and Pt-Rh films are sputter deposited with thermocouple junctions formed by overlapping the two films at the desired spot. The films extend to the base of the vane where leadwires are connected. The sensor is less than 0.001 in. thick. The advantage of this technique over the previous technology, which required swaged thermocouple wires to be buried into grooves cut into the surface, should be obvious. This technology has been developed (Grant and Przybyszewski, 1980, and Grant et al., 1981 and 1982) for turbine airfoil temperature measurement. Further work has been directed at other sensor types, other sensor and substrate materials, and maturing the technology (Grant et al., 1983; Kreider et al., 1984; Kreider and Semancik, 1985; Prakash et al., 1985; and Budhani et al., 1986a and 1986b).

- **MEASURE SURFACE TEMPERATURE OF COOLED TURBINE AIRFOILS**
- **FABRICATION: SPUTTER ALLOY FILM LEADS OVER INSULATING COATING ON AIRFOIL SURFACE**
- **SENSOR THICKNESS, $<$0.001 in.**



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HIGH-TEMPERATURE STRAIN MEASURING SYSTEMS

The most ambitious goal of the research sensor program is development of high-temperature (1800 °F) strain measuring systems. Approaches being followed in this work include both wire and thin-film resistance strain gages and remote measuring systems. Our resistance strain gage work has included work on new strain gage materials (Hulse et al., 1985 and 1987a; and Lei, 1987) and testing of available strain gages, including the Chinese 700 °C gages (Hobart, 1985; Stetson, 1984; and Hulse et al., 1987b). Work on remote strain measuring systems has involved three different system concepts based on laser speckle patterns (Stetson, 1983; and Lant and Qaqish, 1987a and 1987b).

- **GOAL:**

  MEASURE STATIC STRAIN ON TEST SAMPLES AND TURBINE ENGINE COMPONENTS AT TEMPERATURES UP TO 1800 °F

- **APPROACHES:**

  RESISTANCE STRAIN GAGES—
  WIRE GAGES
  THIN-FILM GAGES

  REMOTE STRAIN MEASURING SYSTEM—
  LASER SPECKLE BASED SYSTEM

FUTURE THRUSTS IN RESEARCH SENSORS

Future work in research sensors will be strongly influenced by new materials being developed for turbine engine components. These materials are expected to be in the forms of metal and ceramic matrix composites. Both the nature of the materials and the significantly higher hot section temperatures that these materials are expected to make possible will influence our sensor work. If thin-film sensors are to be applied to these materials, methods for producing suitable insulating films must be developed. As surface temperatures rise, the temperature limits of available sensor materials will force more emphasis on remote, noncontact sensing techniques. In addition, we will continue to search for new sensor materials with higher temperature capabilities. Work has already started in these directions relative to surface temperature, strain, and heat flux measurements on ceramic and ceramic matrix composite materials.

MAJOR DRIVER:

- **PROGRAM TO DEVELOP MATERIALS TO OPERATE AT SIGNIFICANTLY HIGHER HOT SECTION TEMPERATURES—METAL- AND CERAMIC-MATRIX COMPOSITES**

EFFECT ON SENSOR PROGRAMS:

- **DEVELOP TECHNOLOGY FOR THIN-FILM SENSORS ON NEW SUBSTRATE MATERIALS**
- **DEVELOP SENSOR MATERIALS FOR HIGHER TEMPERATURE RANGES**
- **IMPROVE REMOTE SENSING TECHNIQUES**

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